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Original Article

Influence of Changes in Bone-Conduction Thresholds on Speech Audiometry in Patients Who Underwent Surgery for Otosclerosis

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OBJECTIVES: Otosclerosis is an underlying disease of the bony labyrinth that results in hearing loss. In some cases, the involvement of the bony part of the cochlea results in mixed hearing loss. The aim of this analysis was to seek a correlation between the results of speech audiometry tests and the changes in bone-conduction thresholds observed after surgical treatment.

MATERIALS and METHODS: The analysis included 140 patients who were hospitalized and surgically treated for otosclerosis. The patients who were treated with stapedotomy were divided into subgroups based on the value of the bone-conduction threshold before the surgery. An audiological assessment was performed, with pure-tone threshold audiometry and speech audiometry tests taken into account.

RESULTS: The effectiveness of the surgery was judged by the change in the speech audiometry test results after 12 months of observation. After the surgery, it was found that a significant improvement, characterized as achieving 100% understanding of speech, occurred in 61.90% of the patients.

CONCLUSION: There is a correlation between the improvement in speech audiometry tests and bone-conduction curve after stapedotomy. The changes achieved in the bone-conduction curve at the frequency range up to 3,000 Hz (hertz) had a significant impact on the improvements in speech audiometry test results. Higher frequencies provide more data for improving the hearing process. A mean bone-conduction threshold between 21 and 40 dB (decibels) in the pure-tone audiometry examination performed before surgery is a favorable prognostic factor in the improvement of the bone-conduction threshold after surgery.

KEYWORDS: Otosclerosis, pure-tone audiometry, bone-conduction thresholds, speech audiometry, cochlear reserve

INTRODUCTION

Otosclerosis is a primary disease of the bony labyrinth and is characterized by progressive hearing deterioration. In the literature, the first report on otosclerosis appeared in 1735. The case described by Antonio Maria Valsalva from Bologna referred to the immobilization of the stirrup plate in the oval window. The definition and concept of otosclerosis as an isolated affliction of the labyrinth capsule was introduced to the otologic terminology by Politzer in 1894.

Effective surgical treatment is reflected in an improvement of the course of the air conduction threshold curve. The area between the air and bone-conduction threshold curve is reduced, which is referred to as the closure of the cochlear reserve. Favorable prognostic factors for improving hearing after surgery on the middle ear are good bone conduction and a large air-bone gap in the audiometry test performed before the surgical procedure [1–5].

In Fleischer's classification, the postoperative outcome is predicted using the mean cochlear reserve measured preoperatively at frequencies of 500, 1,000, and 2,000 Hz in the tonal audiogram (Table 1) [6].

For many years, the classification by G. Shambaugh has also been used, which treats the improvement in hearing as dependent on the preoperative threshold values of bone conduction.

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Table 1. Fleischer's classification

	Preoperative cochlear reserve (dB)	Prognosis
Group I	>35	very good
Group II	25–30	good
Group III	15–20	sufficient
Group IV	<10	uncertain

Table 2. G. Shambaugh's classification

	Bone-conduction threshold values (dB)	Prognosis
Group A	0-15	very good
Group B	16-25	good
Group C	26-35	sufficient
Group D	≥36	uncertain

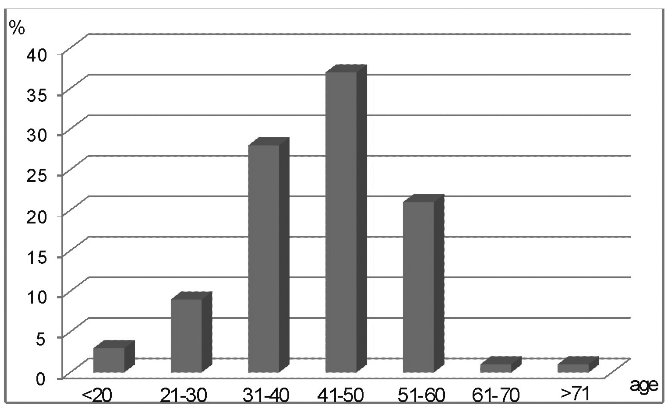

Figure 1. Percentage distribution of age ranges of patients undergoing the analysis.

On the basis of the bone thresholds, one can determine with fairly high accuracy the so-called Shambaugh–Carhart hearing prognosis curve (Table 2) [7].

Currently, the practice of presenting the results of otosclerosis treatment by comparing only the mean cochlear reserves before and after surgery is not recommended. The American Academy of Otolaryngology–Head and Neck Surgery Committee on Hearing and Equilibrium guidelines recommend assessing otosclerosis treatments by analyzing the change in the bone-conduction deficit based on its thresholds at 0.5, 1, 2, and 3 kHz in correlation with the change in the cochlear reserve [8].

Hearing is one of the human senses, and its most important role is the perception and analysis of speech. The treatment of choice for otosclerosis is a surgery aimed at improving ossicular chain movement by using a prosthesis in place of the stapes superstructure. Restoration of right ossicular chain movement after stapedotomy leads not only to changes in the air-bone gap but also to objectively measurable changes in bone-conduction thresholds.

The understanding of speech is an important element in the subjective evaluation of hearing improvement after surgery for otosclerosis.

The aim of this analysis was to determine the correlation between the results of speech audiometry tests with the changes in bone-conduction thresholds observed after stapedotomy surgery.

MAIN POINTS

- Better speech comprehension after stapedotomy correlates with changes in bone conduction thresholds.
- Improvement in the social communication is observed for changes in bone conduction thresholds up to 3000 Hz.
- The primary goal of otosclerosis treatment is not to close the cochlear reserve but to improve speech understanding

MATERIALS AND METHODS

The study included 140 patients who underwent first-time surgery for otosclerosis between 2010 and 2016. The patients' ages ranged from 19 to 71 years old, and the mean age was 39.31 years. The study group was composed of 87 women between 19 and 71 years old (average age, 40.33 years old) and 53 men between 27 and 59 years old (average age, 38.23 years old). Most patients were between 41 and 50 years old. A distinctly lower number of operations were performed in patients over 60 years of age (Figure 1).

In all patients, an interview; a physical otorhinolaryngological examination; and a complete set of audiological examinations, including an audiometric examination, tuning fork tests (with a c2 512 Hz tuning fork), and pure-tone threshold audiometry and speech audiometry tests were performed. The audiometric tests were performed in a sound-proof and sound-absorbent cabin in the audiometric laboratory. In the cabin, the equivalent A-weighting–corrected sound level did not exceed 25 dBA (L Aeq (a-weighted equivalent sound level) = 25.1 dBA). The intensity of the stimulus for each tested frequency was determined with an accuracy of 5 dB. During the examination, the room was occupied only by the patient being examined. Threshold values for air and bone conduction were determined by audiometer equipped with TDK 39 headphones (MIDIMATE 622, Madsen, Dybendalsvænget, Taastrup, Denmark). The audiometer met the International Organization for Standardization (ISO) standards for air (ISO0389-1985) and for bone conduction (ISO7566-1987).

The evaluation of the patient's understanding of speech was carried out using an AAD80 audiometer (Zalmed, Warsaw, Poland) and a Technics amplifier and cassette player (Panasonic, Osaka, Japan). The fluctuations of the signal level did not exceed 1.5 dB, and the signal-to-noise ratio was above 63 dB. To complete the evaluation, the NLA-93 (new articulation list - 93) word test was used. The test material consisted of 10 balanced lists containing 24 monosyllabic nouns in each list. The test was balanced acoustically, grammatically, phonemically, semantically, energetically, and structurally. The test was always carried out by the same person with the same apparatus, and the control values were established based on a study of healthy Poles [9].

The mean air-bone gap and the mean bone-conduction threshold were calculated as the arithmetic mean across the speech frequencies tested (500 Hz, 1,000 Hz, 2,000 Hz, and 3,000 Hz) both before the surgical procedure and 12 months after the operation.

The data collected during the study were statistically analyzed (analysis of variance in Statistica, StatSoft, Cracow, Poland). Fisher's exact test, also known in the literature as the analysis of variance test, which is sometimes used as an alternative to the analysis of variance test for categorical data in the literature. Two-by-two (2x2) multileveled contingency tables (cross-tabulation tables) were used to verify non-parametric hypotheses.

Cramér's coefficient was used to assess the correlation between two variables.

Statistically significant results were indicated when p<0.05.

When analyzing the results of the operation, the patients were grouped based on the type of operation performed: Group A, stapedotomy (N=126 people) and Group B, stapedectomy (N=14 people).

Given the small number of patients for whom a stapedectomy was performed, this group of patients was excluded from further analysis.

Patients were operated on by two otosurgeons using the same surgical technique and with similar experience in the surgical treatment of otosclerosis. Classic stapedotomy was performed for each patient with a piston-like prosthesis with a diameter of 0.6 mm. This procedure allowed the analyzed patients to be treated as a homogeneous group.

The patients who were treated with a stapedotomy were divided into subgroups based on the bone-conduction threshold before the surgery. Owing to the need to create groups of sufficient size that would enable a stronger statistical analysis, Shambaugh's classification (Table 2) was modified, and a division was proposed as shown in Table 3.

The diagrams obtained from the speech audiometry examinations performed before and 12 months after surgery were analyzed for all patients. This resulted in the identification of two groups of patients, those showing an improvement and those showing no improvement in the free-field speech discrimination test.

Table 3. Patient subgroups depending on the initial mean values of bone-conduction thresholds

Subgroups	Initial mean bone-conduction value (dB)	N	%
Subgroup A I	0-20	24	17
Subgroup A II	21-40	82	59
Subgroup A III	>40	20	14

The local ethics committee approved the study (no. 122.6120.206.2016).

RESULTS

On preoperative examination, all patients reported hearing loss, and 81.42% (N = 114 patients) complained of tinnitus. The subjectively perceived hearing loss was unilateral in 27.15% of patients (N = 38) and bilateral in 72.85% (N = 102).

The mean values of the air-bone gap and the mean bone-conduction thresholds, both at the beginning of the treatment and after 12 months of observations, were analyzed for the different bone-conduction groups (Table 4). Twelve months following the surgery, the change in the mean air-bone gap with respect to the presurgical gap was statistically significant in each of the bone-conduction groups. Simultaneous analysis of the changes in the mean air-bone gap between particular groups did not show a significant difference.

In the analysis of changes in the mean bone-conduction threshold over the 12-month observation period, a statistically significant improvement was observed in the A II group. The change in the mean value of the bone-conduction threshold in the A I and A III groups after the same period of time was not statistically significant (Table 5).

In addition, irrespective of the previous division of the patients, those that showed an improvement in the results of the speech audiometry test after surgical treatment were examined.

In the preoperative evaluation, 42.14% of patients had a 100% understanding of speech, and 57.86% of patients did not have full understanding of speech. In 18.57% of the patients, the articulation curve assumed the shape of a bell (in terms of speech audiometry test results, this shape is characteristic of cochlear involvement in perceptive hearing loss), and in 81.43%, it had a slanted course (typical of conductive hearing loss in speech audiometry test results).

Table 5. Change in mean air-bone gap and mean bone-conduction threshold value 12 months after surgery

	Δ ABG	SD	Δ BC	SD
Gr. A I	18.55	12.40	−0.8	16.20
Gr. A II	18.50	12.00	5.70	12.70
Gr. A III	17.4	11.85	0.5	10.10

Δ ABG: change in the mean air-bone gap after 12 months of observation; Δ BC: change in the mean bone-conduction threshold value after 12 months of observation; Gr: group; SD: standard deviation.
Statistically significant changes marked in bold (p<0.05).

Table 4. Mean values of the air-bone gap and mean values of bone-conduction thresholds at the beginning of treatment and after 12 months of observation in bone-conduction thresholds groups

	ABG 0	SD	ABG 12	SD	BC 0	SD	BC 12	SD
Gr. A I	34.05	11.00	15.50	8.39	19.20	2.8	20.00	6.80
Gr. A II	31.20	9.50	12.70	10.62	33.20	7.5	27.50	12.20
Gr. A III	34.50	9.70	17.10	15.47	47.00	5.2	46.50	19.50

ABG 0: mean air-bone gap before surgery; ABG 12: mean air-bone gap after 12 months of observation; BC 0: mean value of bone-conduction thresholds before surgery; BC 12: mean value of bone-conduction thresholds after 12 months of observation; Gr.: Group; SD: standard deviation.
Statistically significant changes after 12 months of observation marked in bold. (p<0.05).

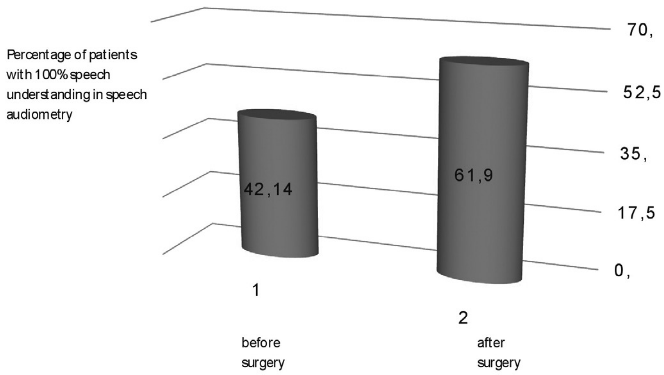

Figure 2. 100% understanding of speech in speech audiometry before and after surgical treatment.

Table 6. Change in the mean value of bone-conduction thresholds in the group of patients with improvement in speech audiometry (analysis in the frequency range 500 Hz, 1,000 Hz, 2,000 Hz, and 3,000 Hz)

	Mean BC	Δ BC	SD	N	p
BC 0 (500 Hz)	28.24	—	12.24	78	—
BC 12 (500 Hz)	20.00	8.24	11.18	78	0.003
BC 0 (1,000 Hz)	32.65	—	9.53	78	—
BC 12 (1,000 Hz)	23.53	9.12	15.59	78	0.001
BC 0 (2,000 Hz)	15.50	—	10.62	78	—
BC 12 (2,000 Hz)	20.00	10.50	13.93	78	0.001
BC 0 (3,000 Hz)	27.5	—	12.48	78	—
BC 12 (3,000 Hz)	22.00	5.50	14.53	78	0.017

BC: bone-conduction threshold; Δ BC: change in the mean bone-conduction threshold value after 12 months of observation; SD: standard deviation.
Statistically significant changes marked in bold (p<0.05).

Table 7. Change in the mean value of bone-conduction threshold in the group of patients showing poorer results in speech audiometry following the surgery (analysis in the frequency range 500 Hz, 1,000 Hz, 2,000 Hz, and 3,000 Hz)

	Mean	Δ BC	SD	N	p
BC 0 (500 Hz)	32.14	—	10.93	48	—
BC 12 (500 Hz)	28.28	2.86	11.45	48	0.09
BC 0 (1,000 Hz)	34.57	—	12.09	48	—
BC 12 (1,000 Hz)	32.14	2.43	12.73	48	0.17
BC 0 (2,000 Hz)	45.54	—	18.67	48	—
BC 12 (2,000 Hz)	41.00	4.54	18.42	48	0.01
BC 0 (3,000 Hz)	47.23	—	18.70	48	—
BC 12 (3,000 Hz)	43.10	4.13	18.49	48	0.07

BC: bone-conduction threshold; Δ BC: change in the mean bone-conduction threshold value after 12 months of observation; SD: standard deviation.
Statistically significant changes marked in bold (p<0.05).

The effectiveness of the surgery was judged by the change in the speech audiometry test results after 12 months of observation; it was found that a significant improvement, characterized as achieving 100% understanding of speech, occurred in 61.90% of the patients. In 11.43% of the patients, the articulation curve continued to take the shape of a bell, and in the remaining 88.57%, it continued to be slanted (Figure 2).

The correlation between the changes in the speech audiometry results and the changes in the bone-conduction threshold was analyzed in the group of patients with improvements in the speech audiometry test results after 12 months of observation (Table 6). The results showed a statistically significant change in the bone-conduction threshold value for the studied frequencies ($p < 0.05$). The patients achieved 100% understanding of speech in the examination carried out 12 months after surgery.

The results for the group of patients with poorer results in speech audiometry following the surgery were examined with analysis of variance (Table 7). Compared with the presurgical values, the mean bone-conduction thresholds at 500 Hz, 1,000 Hz, and 3,000 Hz obtained 12 months after the operation were not significantly different ($p > 0.05$). At 2,000 Hz, a statistically significant improvement in the mean bone-conduction threshold was found ($p<0.05$).

DISCUSSION

Konopka et al. [10] noted that in numerous publications reporting the results of the treatment of this disease, the main emphasis was on the assessment of the closure of the air-bone gap and not on the assessment of speech understanding [11-14]. However, it should be remembered that the primary goal of otosclerosis treatment is, in fact, not to close the cochlear reserve but to improve speech understanding.

Bone conduction is a complex and multicomponent process. It is impossible to explain the observed changes using one mechanism. Bone-conduction thresholds in otosclerosis may be affected by various factors, such as proteolytic enzymes released from otosclerotic lesions in the bone tissue adjacent to the cochlea, damage to the sensory-nervous apparatus, deterioration over time, or the Carhart effect. The analysis of the correlation of bone-conduction thresholds with changes in the results from the speech audiometry tests showed that, in groups in which significant improvement in the speech audiometry results had been achieved, a statistically significant improvement in the mean bone-conduction threshold was observed. When carried out in the group of patients with no improvement in speech audiometry, the same analysis did not reveal a significant improvement in the mean bone-conduction threshold at 500 Hz, 1,000 Hz, and 3,000 Hz. However, a statistically significant improvement occurred at 2,000 Hz. This improvement has no significant effect on the final result of the speech audiometry test. This is explained by the phenomenon of redundancy, described by Bocca and Callearo [15], which characterizes all-natural languages and refers to the full content of information in the transmitted verbal material. A common conclusion reached by various research centers indicates that for the national language, an improvement in the bone-conduction thresholds at frequencies higher than 3,000 Hz is not important in terms of understanding speech [15]. On the other hand, according to the literature, higher frequencies provide a set of additional data that are very important for the quality of hearing (the naturalness of speech and music signals) [16, 17]. The results obtained here require further analysis with regard to comparisons with other studies.

CONCLUSION

There was a correlation between the improvement obtained in the results from speech audiometry tests and the improvement in the bone-conduction threshold curve after stapedotomy.

The changes achieved in the bone-conduction curve at frequencies up to 3,000 Hz had a significant impact on the improvement in the speech audiometry test results. Higher frequencies provide more data to improve the hearing process.

A mean bone-conduction threshold between 21 and 40 dB in the tonal audiogram performed before surgery is a favorable prognostic factor in the improvement of bone-conduction thresholds after surgery.

Ethics Committee Approval: Ethics Committee Approval was received for this study from the Ethics Committee of Jagiellonian University (27.06.2016-122.6120.206.2016).

Informed Consent: Written informed consent was obtained from each participant of the study.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – A.W.; Design - A.W., M.W.; Supervision - M.W.; Resource - A.W., M.W.; Materials A.W., M.W.; Data Collection and/or Processing - A.W., M.W.; Analysis and/or Interpretation - A.W., M.W.; Literature Search M.W.; Writing - A.W.; Critical Reviews - M.W.

Conflict of Interest: The authors have no conflict of interest to declare.

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